

presence of tourmaline in quantity—and associated with garnet—has been long since noted (e.g. Lohest, 1911). The Lower Palaeozoic sediments of the Stavelot Massif are, it would seem at a distance, a very possible source of tourmalinite pebbles.

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## An isotropic alteration product of cordierite

THE most usual alteration products of cordierite are white mica (pinitite) and chlorite, but there have been several records of brownish and yellowish isotropic alteration products. Analyses of low-potash alteration products are few (e.g. Dana, 1892, p. 421; Chandler, 1975), but they show considerable variety. Examples of brown and yellow isotropic alteration products have been reported in the Cape Province of South Africa (Mathias, 1952); in the Chipata district of eastern Zambia (Vavřda and Vrána, 1972) and nearby in the Mchinji district of Malawi (Haslam, 1980); further north in Malawi, in the Champira Dome (Haslam *et al.*, 1980); in the Loos-Hamra region of Sweden (von Eckermann, 1936); and in NE Scotland (Ashworth, 1976). This communication describes the Champira Dome occurrence, and gives some data for the Mchinji occurrence.

Cordierite is an important constituent of migmatites and banded quartzofeldspathic gneisses in the Champira Dome, Malawi (12° 20' S, 33° 38' E). Minerals commonly associated with it are quartz, orthoclase microperthite, sodic plagioclase, almandine, biotite, sillimanite, magnetite, hercynite, corundum, ilmenite, and hematite (Haslam *et al.*, 1980). Several of the rock specimens examined

contain a yellowish isotropic substance with a glassy appearance. In most instances it is clearly a replacement product of cordierite, initially replacing it along fractures and grain boundaries, but in a few specimens it forms pseudomorphs after biotite.

In thin section the substance is pale yellow and optically isotropic. It has a clear, vitreous appearance and inclusions are generally scarce or absent. It is common for Becke lines to be discernible within the material, indicating a slightly heterogeneous composition. The refractive index is greater than that of quartz, and hand-picked grains from MB 60 showed a refractive index of  $1.565 \pm 0.005$ . A grain from the same specimen had a low specific gravity of  $2.51 \pm 0.02$ , consistent with a loosely packed amorphous structure.

No transitional phases are visible between the isotropic substance and cordierite or biotite, nor are there any reaction textures with other minerals. Its formation was not accompanied by hydrothermal alteration of other minerals. Relic cordierite and biotite are generally fresh, and so are adjacent crystals of feldspar. One specimen (MB 65) shows hydrothermal alteration, and cordierite, feldspars, and isotropic substance alike display

patches of sericitization, accompanied in some places by kaolinization, but it cannot be deduced from the textural evidence whether the hydrothermal alteration preceded or succeeded the formation of the isotropic substance from cordierite.

The textural relationships in some specimens (e.g. MB 60) show the isotropic substance as a pseudomorph of biotite. The similarity with the material derived from cordierite, however, both in appearance and in chemical composition (Table I), make it improbable that different parent minerals could have been involved. Some of the cordierite in this suite of rocks developed by replacement of biotite (Haslam *et al.*, 1980), and it thus seems likely that the biotite in MB 60 was partially replaced by cordierite, and that the latter mineral was subsequently replaced by the isotropic substance.

TABLE I. *Electron microprobe analyses of isotropic cordierite alteration (standard deviations in parentheses)*

	1	2	3
SiO <sub>2</sub>	38.1 (0.8)	40.0 (0.6)	44.5 (0.8)
TiO <sub>2</sub>	< 0.01	< 0.01	0.01 (0.003)
Al <sub>2</sub> O <sub>3</sub>	35.1 (0.4)	36.0 (0.3)	40.3 (0.4)
FeO*	6.4 (0.3)	5.4 (0.2)	2.1 (0.1)
MnO	0.04 (0.002)	0.06 (0.02)	0.01 (0.005)
MgO	5.5 (2.1)	5.6 (0.8)	0.03 (0.07)
CaO	0.8 (0.1)	0.8 (0.1)	0.14 (0.06)
Na <sub>2</sub> O	1.0 (0.5)	0.3 (0.1)	0.04 (0.03)
K <sub>2</sub> O	0.4 (0.1)	0.3 (0.1)	0.3 (0.02)
H <sub>2</sub> O†	12.7	11.5	12.6

1. Yellow isotropic substance associated with biotite, MB 60, Champira Dome (median of four analyses).
2. Yellow isotropic substance associated with cordierite, MB 62, Champira Dome (median of four analyses).
3. Yellow to brown isotropic substance, HH 202, Mchinji (median of three analyses).

\* Total iron as FeO.

† Values obtained by difference.

Analyses carried out using techniques and standards described by Bowles (1975).

Electron microprobe analyses of the isotropic material in MB 60 and MB 62 are presented in Table I. Spectra obtained using an energy dispersive analyser showed no trace of elements other than those determined in the analysis; the low total must therefore be due to the presence of elements lighter than sodium, and it is presumed that H<sub>2</sub>O constitutes all or nearly all the balance. Each analysis represents the median of analyses obtained from two different areas of the section. The analyses obtained from the two specimens are very alike, and there is also little variation within each specimen. In particular, (a) the TiO<sub>2</sub> content is extremely

low—lower than in the associated cordierite in MB 62 (0.02%), (b) the CaO content, though less than 1%, is significantly higher than in the cordierite (< 0.01%), and (c) the K<sub>2</sub>O content is significantly greater than in the cordierite (< 0.1%).

An X-ray diffraction powder photograph of grains from MB 60 showed lines characteristic of a dioctahedral kaolinite group mineral, together with traces of other crystalline phases (probably illite and quartz). A smaller quantity of material from MB 63 (similar to MB 62 and from a field locality 50 m away) yielded a similar but weaker and less diagnostic powder pattern. The appearance of the isotropic material in thin section suggests that, rather than being a direct replacement product of the cordierite, the kaolinite may have formed by partial ordering in a wholly amorphous primary alteration product.

Cordierite in banded quartz-sillimanite hornfels in the Mchinji district of Malawi (13° 47½' S., 32° 48' E.) is mostly replaced, some grains by sericitic aggregates and some by isotropic material (Haslam, 1980). Three grains replaced by the isotropic substance were analysed by electron microprobe, one pale brownish yellow, one medium brown, and one darker brown. The results for the three grains are very alike, and the median is shown in Table I, analysis 3. SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> are higher than in the Champira Dome analyses; water, calculated by difference, is about the same, and the other determined elements total only about 2.6%.

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## ADDENDUM

Since this note was accepted for publication, the author has read the discussion of similar material from the French Massif Central. Nédélec and Paquet (1981) describe an isotropic substance in high-grade gneisses, which they believe to be a glass resulting from incongruent melting of biotite. Clemens and McMillan (1982) and Marchand *et al.* (1982) express doubts about the laboratory work and interpret the substance as an alteration product of cordierite, but Nédélec and Paquet (1982) stand by their earlier results. The Massif Central and Champira Dome occurrences are similar in chemical composition, and also have in common a high-grade metamorphic setting, a vitreous appearance in thin section, and an apparent reaction relationship with biotite. The present author considered the possibility that the Champira Dome material was a glass, quenched from a melt formed from biotite and cordierite during metamorphism, but this hypothesis had to be rejected because the geological environment did not permit the rapid cooling needed to quench a liquid, the chemical composition was not consistent with a metamorphic melt, and the substance closely resembled cordierite alteration products described from other areas. For the same reasons, the interpretation of the Massif Central occurrence as a quenched melt cannot be sustained, but

Nédélec and Paquet have none the less helped to characterize the isotropic substance. Their TEM observation (1982) of 'minute crystals of kaolinite, about 1000 Å in size, embedded in a glassy matrix' offers a model that would (with 'amorphous' substituted for 'glassy') satisfactorily account for the observed properties of the Champira Dome material. The alteration of cordierite to this amorphous substance may thus be distinct from its alteration to white mica and/or other phyllosilicates, the different forms of alteration presumably taking place under different conditions, and the isotropic material which Schreyer and Yoder (1961) found to consist of 'a 1 M muscovite and a 7 Å phase (aluminous serpentine or septechlorite)' may represent incipient crystallization from an amorphous substance.

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## Wroewolfeite in SW England

THE recently described copper sulphate hydroxide hydrate, wroewolfeite (Dunn and Rouse, 1975), has been found at two locations in SW England. These are Devon Friendship Mine, Marytavy, Devonshire, and Penberthy Croft Mine, St. Hilary, Cornwall. These mines were worked for copper together with a little tin and lead, and the lodes at both localities show certain similarities in their mineralization, containing fair amounts of calcium carbonates.

At Devon Friendship Mine wroewolfeite was found on old dumps on the western side of the stream that cuts through the mine workings situated southeast of the village of Marytavy. These dumps contain a large amount of decomposing chalcopyrite- and pyrite-bearing material, and also quantities of galena and calcite veinstuff from the north-south trending lead lode that was worked in the mine apart from the major east-west copper lodes. The wroewolfeite occurs as beautiful

greenish-blue to sky-blue sharp transparent monoclinic crystals scattered on open joints in a dark slaty veinstone, with speckles of chalcopyrite and later veinlets of quartz and calcite. The crystals range in length from 1 to 2 mm. Another form found on one specimen consists of radiating aggregates of flattened tabular crystals of a pale sky-blue colour attaining 5 mm in length, implanted on a joint in quartz. Crystalline crusts of bright green brochantite occur on some specimens.

At Penberthy Croft Mine wroewolfeite occurs on dumps in the eastern section of the mine. It is found as small light blue scales and poorly formed crystals rarely larger than 2 mm in size, scattered on joints and in cavities in weathered brecciated slate and dolomite veinstuff with threads of chalcopyrite.

At both localities wroewolfeite has formed in the dumps as a result of weathering of chalcopyrite-bearing veinstuff, and it appears that calcium